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ORIGINAL PAPER

Effect of human disturbance on the structure and regeneration of forests in the Nevado de Toluca National Park, Mexico

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Abstract: Sample plots were established in the principal forest types in the the Nevado de Toluca National Park, Mexico including those dominated by *Pinus hartwegii*, *Abies religiosa*, *Quercus laurina* and *Alnus jorullensis*. The vertical structure was defined by three strata in the coniferous forests and two strata in the broadleaved forests. Timber harvesting in *Abies religiosa* and *Quercus laurina* forests and fires generated by humans in *Pinus hartwegii* forests impeded the recruitment of saplings. Mature trees were also heavily impacted by logging in *Pinus hartwegii* forests. On the contrary, *Alnus jorullensis* forests were increasing due to the disturbance of *Pinus* and *Quercus* forests, as well abandoned crop lands within the park. A combination of logging, uncontrolled fire, and grazing appears to be compromising the recruitment of important tree species in this national park. These factors, together with human settlements, have also increased the proportion of early successional species. Changes in forest structure from human disturbance indicate a need to control these activities if conservation goals are not to be compromised.

Keywords: forest structure; human disturbance; mountain forests

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Introduction

In recent decades, human activities have become the principal cause of disturbance to natural ecosystems (Vitousek et al. 1997), including the destruction, fragmentation and degradation of habitats which has caused changes in ecosystem structure and function (Saunders et al. 1991; Child 2004). The increasing impact of human disturbance has led to the creation of many protected areas, such as natural parks and nature reserves. Unfortunately, humans are also negatively impacting protected areas either due to a failure or inability to prevent anthropogenic disturbances. For example, managers of natural parks are often powerless to prevent regional air pollution damage (Alvarado et al. 1993; Percy and Karnosky 2007) with protected areas, as well as other disturbances that occur on lands adjacent to them. Isolation of protected areas and invasive plant species or exotic animal species can infiltrate protected areas from adjacent lands (Macdonald et al. 1988). In some cases, protected areas are besieged by human invasions that both managers and governments and are unable or unwilling to control (Bobbink et al. 2003; Pacheco 2006; Timko and Innes 2009). In some newly created protected areas, inholdings may exist with landowners having legal rights to resource use within the protected area (Nagendra et al. 2006). In developing countries, it is common to have grazing, logging, and other extractive activities occur in protected areas by local populations (Sahu et al. 2008). All of these factors may compromise conservation objectives of the park, but relatively few studies have analyzed the impact of these factors through studies of existing plant community structure and composition.

Mexico is one of the mega diverse countries in the world (Mittermeier et al. 1998) which it is covered about 11% by federal natural protected areas (NPAs) (22.71 million ha). The NAPs have been addressed to conservation strategies of ecosystems (CONANP 2007), but there is still lack of information related to the effectiveness of Mexican NPAs in order to prevent particular

threats on the land use and cover change, mostly caused by human pressure (Román and Martínez, 2006).

The analysis of the structure, regeneration, and growth of forest ecosystems in protected is important to determine how human disturbances may impact existing vegetation or natural succession (Aguirre et al. 2003). Bobbink et al. (2003) found a relatively high impact of human disturbance during a relatively brief (1986-1997) period within the Iztaccíhuatl-Popocatepetl Park in México where they estimated a reduction in forested area of 13.2%, including an increase in forest fragmentation. The principal causes of this forest loss and fragmentation included an increasing frequency of wildfires associated with cattle grazing, illegal logging, and an increase in illegal human settlements. Such a loss within a protected area may require an assessment of impacts on biodiversity and a revision of resource management plans.

Nevado de Toluca National Park (NTNP) is an important protected area in the state of México. The park has suffered a loss in the area of mature forest at a rate of 156 $ha \cdot a^{-1}$ between 1972–2000, including a 40% loss in pine forest area (Franco et al. 2006). The loss of forest area was mainly due to illegal logging of *Pinus hartwegii* and *Abies religiosa* (Villers et al. 1998; Endara 2007). Lately, logging has also occurred in forests dominated by *Alnus jorullensis* and *Quercus laurina.*

The loss of *Pinus hartwegii,* an endemic species to high-elevation forests in Mexico, due to logging in NTNP along with subsequent cattle grazing and wildfire could compromise the conservation goals of the park. Studies on the impact of these disturbances on remaining forests is important for developing a conservation plan for the park and for understanding the effects of human disturbance on the ecological integrity of protected areas in general. The objective of this study was to evaluate the impact of logging, cattle grazing, and wildfire on the structure, species composition, and regeneration of forests in NTNP.

Methods

Study site

Nevado de Toluca National Park which was created in 1936 is located in southwest of the Valle de Toluca and is delimited by the 3 000 m summit of the Xinantécatl volcano (Fig.1).

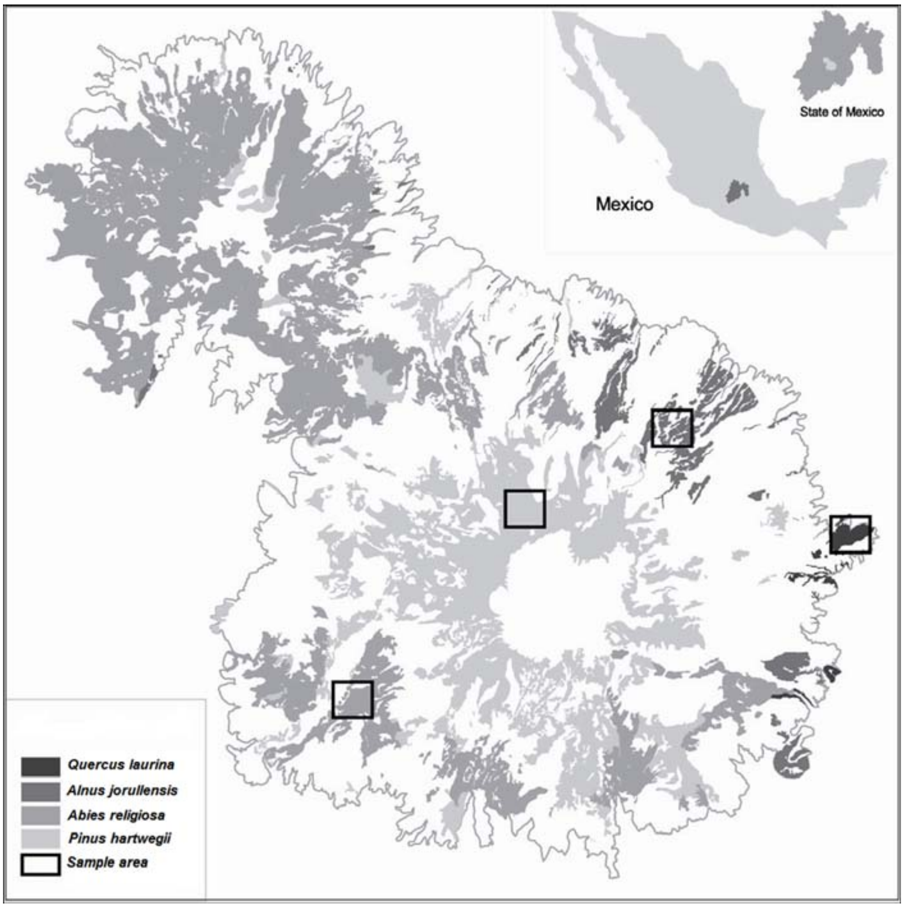

Fig. 1 Location of Nevado de Toluca National Park.

The park covers approximately 51 000 ha and includes parts of the municipalities of Zinacantepec, Villa Guerrero, Temascaltepec, Amanalco, Villa Victoria, Almoloya de Juárez, Toluca, Calimaya, Coatepec de Harinas and Tenango del Valle. The

climate is temperate subhumid with an average annual temperature of 17.3°C an average annual precipitation of 800 mm (GEM, 1999). Most rainfall occurs during the summer months (June to September).

Species selection

Using a soil use map for 2000 (Franco et al. 2006), conifer forest types (*Pinus* spp. and *Abies religiosa*) and deciduous forest types (*Alnus jorullensis* and *Quercus laurina*) were identified and verified in the field using a global positioning system.

Plot sampling

A total of thirty sampling plots were established including ten in *Pinus* forests, ten in *Abies* forests, five in *Alnus* forests and five in *Quercus* forests. Using the methods of Villavicencio and Valdez (2003), we installed a 20 m × 50 m plot at each site parallel to the slope where all individual trees > 2.5 cm DBH were measured. Each plot was divided into 10 m × 50 m subplots and on the left-sided plot, the number of individuals < 2.5 cm DBH was measured (these plots were considered as seedlings and saplings). The DBH and total height of all individuals were measured. Regeneration was categorized using the system proposed by Valdez (2002) as seedlings (< 30 cm in height), small saplings (≥ 30 cm < 1.5 m in height) and large saplings (≥ 1.5 m in height < 2.5 cm of DBH).

Horizontal and vertical structure

Horizontal structure of each forest type was determined by grouping individual trees by diameter classes in intervals of 5 cm (2.5−7.4, 7.5−12.4, 12.5−17.4, etc) to graphically portray the diameter distribution. Vertical structure was characterized by comparing heights of all individuals between diameter classes using a one-way analysis of variance. Canopy strata were identified by significant differences in heights between diameter classes.

Forest harvesting assessment

In each 20 m × 50 m plot, the basal diameter of all cut stumps was measured. The purpose of the cutting (sanitation, legal logging, illegal logging) was not identified.

Results

Pinus hartwegii

The vertical structure of this forest is represented by three strata with significant differences in tree height ($p < 0.05$). Despite growing at high altitudes with wide fluctuation in temperatures, the upper stratum can reach 30 m (Fig. 2). Considering the number of individuals by diameter class, the abundance curve was in the form of an inverted J (Fig. 3) which is typical of primary forest (Lamprecht 1990). The curve, however, shows a large number of seedlings and small saplings, but a lack of large saplings indicating that the frequent fires that occur in this forest may be allowing for new recruitment, but only limited advancement beyond the small sapling stage. This lack of recruitment may create problems for forest canopy replacement particularly in an environment with increasing fire and grazing pressure in the understory (Miranda and Hernández 1985). On the other hand, because of a lack of fire in pure forests, as well as in high-altitude forests of *Abies religiosa* and other species, *Pinus hartwegii* is displaced (Ern 1973).

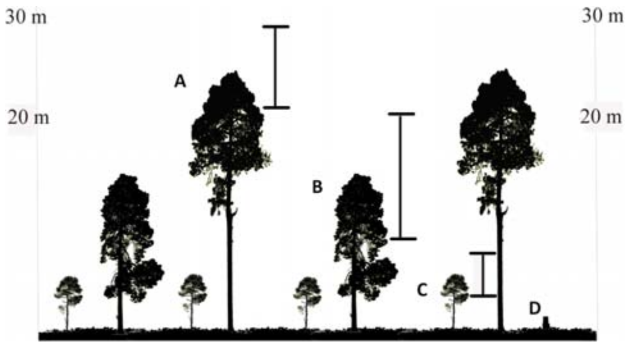

Fig. 2 Vertical structure of *Pinus hartwegii* stands

A= Upper canopy, average height 24 m, DBH > 35 cm; B= Midstory layer, average height 14 m, DBH = 15 – 30 cm; C= Understory, average height 3.5 m, DBH 5 – 10; D= Cut stems

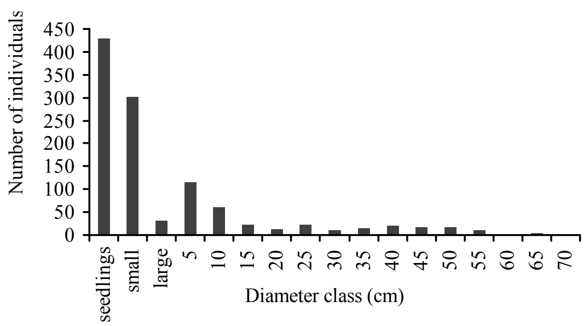

Fig. 3 Horizontal structure of *Pinus hartwegii* stands

The density of individual stems averages 336/ha (≥ 2.5 cm DBH). It is important to consider, however, that harvesting has removed 43 stems/ha (11%), mostly in the range of 10−30 cm DBH, used mostly for firewood.

Abies religiosa

The vertical structure of these forests has three distinct strata ($p < 0.05$) (Fig. 4), with the trees in the upper stratum reaching heights of 48 m. The forest canopy is closed and there is a high level of competition for light which tends to favor growth in height over that of diameter (Swanson and Franklin 1992). A characteristic of this species is that trees can reach heights of 20 m but still have a DBH of < 20 cm.

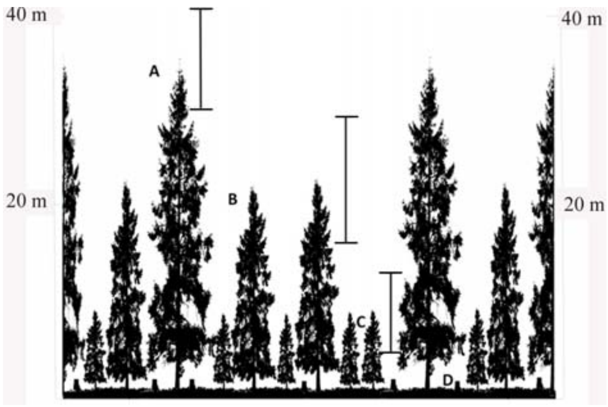

Fig. 4 Vertical structure of *Abies religiosa* stands

A= Upper canopy, average height = 36 m, DBH > 35 cm DAP; B= Midstory, average height = 23 m, DBH = 15 – 30 cm DAP; C= Understory, average; height = 7 m, DBH 5 – 10 cm DAP; D= Cut stems

For a visual representation of vertical stratification, original photographs of each species were used in a profile of 5 x 50 m

The density of stems reaches 637/ha (≥ 2.5 cm DBH), but the number of harvested stems is 271/ha (30%), mostly in the range of 5-30 cm DBH. Villers et al. (1998) noted that illegal logging is the principal disturbance affecting these forests. The horizontal structure (Fig. 5) reveals a lack of seedlings and small saplings. The frequency of harvesting may cause damage to advance regeneration, but it has also been observed that soil scarification may favor the germination of new seedlings of this species (Granados 1995).

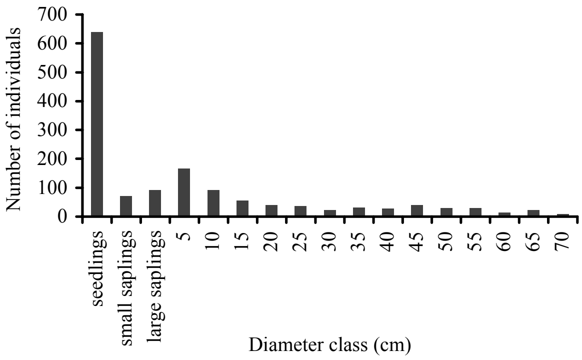

Fig. 5 Horizontal structure of *Abies religiosa* stands

Alnus jorullensis

Due to the low height reached by this species, the vertical structure only contains two distinct strata (Fig. 6). The upper canopy contains trees reaching a maximum height approaching 20 m. Stands of this species are devoid of new seedlings and have few older seedlings or young saplings (Fig. 7). This pattern is typical of this early successional species which often occurs following the removal of pine and oak forests or abandoned fields (Rzedowski 1978). Stand density averages 572/ha (≥ 2.5 cm DBH). The number of harvested stems averages 28/ha (5%), typically in the diameter range of 10–30 cm.

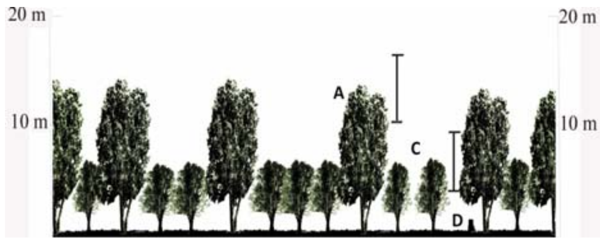

Fig. 6 Vertical structure of *Alnus jorullensis* stands

A= Upper canopy, average height = 13 m, > 10 cm DBH; C= Lower canopy, average height = 6 m, 5 – 15 cm DBH; D= Cut stems.

For a visual representation of vertical stratification, original photographs of each species were used in a profile of 5 x 50 m

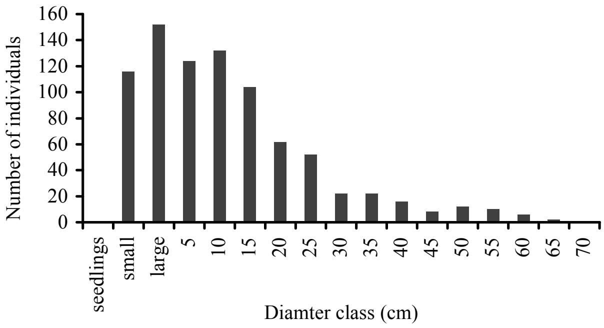

Fig. 7 Horizontal structure of *Alnus jorullensis* stands

There are large areas of mature *Alnus* stands in the NPNT and other areas with new regeneration, but it is rare to encounter them together.

Quercus laurina

The vertical structure of *Quercus* stands (Figure 8) is similar to that of *Alnus* with two distinct strata. The tallest trees in these stands reach 22 m, although the average height is 14 m. Included in these stands, however, are also *Pinus ayacahuite* trees with a density of 14/ha, some of which reach 40 cm in DBH and heights 25-30 m. *Cupressus* sp, also occurs in these stands with a density of 6 stems/ha.

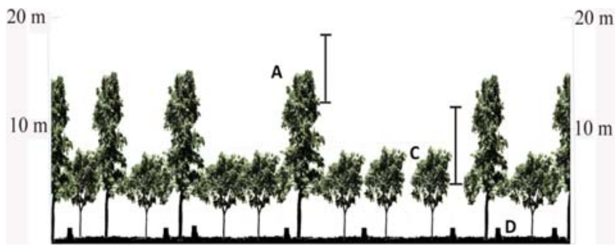

Fig. 8 Vertical structure of *Quercus laurina* stands

A= Upper canopy, average height = 15 m, DBH > 20 cm; C= Lower canopy, average height = 8 m, DBH 5–15 cm; D= Cut stems. For a visual representation of vertical stratification, original photographs of each species were used in a profile of 5 × 50 m.

Tree density averages 758/ha and the number of trees ex-

tracted averages 314/ha (29%), usually within the range of 5-30 cm DBH. The regeneration of this specie is abundant, coming mostly from the sprouts of cut stumps (60%). The resprouting of this specie is responsible for the understory layer (Fig. 9) and causes an inverted J pattern in the diameter distribution. This type of regeneration however will likely change the structure of this forest to one with a large number of smaller-diameter stems with a clumped formation.

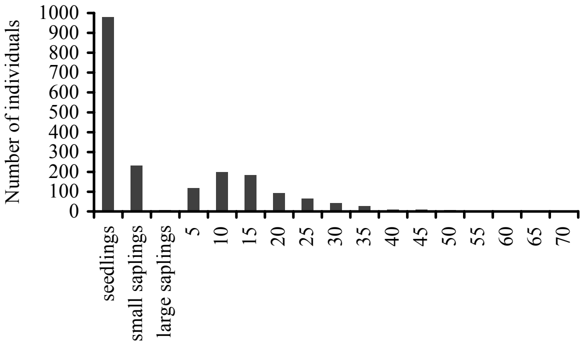

Fig. 9 Horizontal structure of *Quercus laurina* stands

Discussions

This study demonstrates the effects of timber harvesting and fire on the structure on regeneration of forests in NTNP. Harvesting, particularly *Abies religiosa* and *Quercus laurina*, occurs both legally and illegally principally for construction wood, firewood, and fence posts. Harvesting opens the canopy of these forests and increases the abundance of seedlings and saplings. Therefore, frequent fires have originated new open areas used as grass forage for sheep and cattle, as a consequence, negatively affect tree regeneration, particularly the recruitment to the sapling stage. The most negative impacted forests stands by fire are those of *Pinus hartwegii*, furthermore, harvesting, fire, grazing, and shifting agriculture tend to promote the expansion of *Alnus* forests at the expense of pine and oak forests. *Alnus* forests and other types of natural succession species may eventually replace forest stands of pine and oak (Kumar and Ram 2003).

The current state of the forests in NTNP is affected by the selective logging of a few species and a fragmentation of forest cover. The creation of forest gaps increases light availability and temperature, while decreasing relative humidity (Murcia, 1995), in addition, these species will be unavailable to maintain the original structure in long term (Tabarelli et al. 1999), and as a result the structure and composition of the forest will change to the establishment of new tree species (Simonetti et al. 2001).

The conversion seems to accelerate *Alnus*, which is natural with respect to succession, but a sign of too much disturbance, at least for a NTNP which has a conservation goal of maintaining natural forests and their original biodiversity. In this case does not seem to show a decrease in germination or recruitment of new seedlings, the problem seems to be lack of recruitment of saplings due to grazing and/or frequent fire, depending on the species.

The extraction of individuals of pine suggest a considerable reduction in its density population of which coincide with those reported by Franco et al (2006) who attribute this decline to selective logging of the best individuals for commercial purposes, leaving, a residual forest with trees of low quality, which involves a loss of genetic diversity.

The extraction of fir and oak forest, as well as the fire in pine forest, could provoke a shift in the future generations in a long term, in other words, the areas will be dominated by old and young trees. These areas will be more susceptible to pest and diseases.

Throughout the study, it is confirmed that NTNP contains tree species that play an important role in conservation issues. This contribution, however, may not be sustainable, due to the lack of recruitment of saplings due to grazing and/or frequent fire, depending on the species that limits natural regeneration and sometimes requires cutting trees which compromise the future of NTNP, which farmers recognise is reducing the abundance of these important species. In addition, this information could be essential in order to convince decision makers to develop and understand that vegetation changes, to establish policies which have to be addresses to maintain the natural forests and promote forest management programmes. As have been mentioned by King and Peralvo (2010) that concerns about the impacts of national parks and protected areas upon local populations have generated significant interest in community conservation initiatives that attempt to include local knowledge and participation in natural resource decision-making.

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